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A COMPUTER METHOD FOR THE CALIBRATION OF A PHOTOGRAPHIC EMULSIO--ETC(U)
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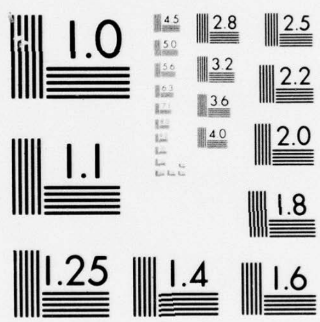


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# A COMPUTER METHOD FOR THE CALIBRATION OF A PHOTOGRAPHIC EMULSION FOR SPECTROGRAPHIC ANALYSIS

BERNARD H. STRAUSS
POLYMER AND CHEMISTRY DIVISION



January 1977



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## ABSTRACT

A computer method to calibrate emulsion-covered glass plates used to interpret densities of lines for quantitative spectrographic work is reported. This method follows a slightly modified ASTM graphic method, which is also described, and allows one to simply input dark and light data points to establish preliminary and emulsion calibration curves. After the curves are established, by inputting percent transmission data pairs for a known or unknown concentration line and an internal standard line, one obtains the relative intensity. The computer method is used on a Hewlett-Packard Calculator 9830-A and a UNIVAC 1108 time-sharing computer. Programs for both computers are included in this report.

CONTENTS

## INTRODUCTION

In the past ten years, many reports have been published concerning the application of computer programming for the calibration of photographic emulsions. Calculating boards[1] and rules[2] have essentially been replaced by readouts from large and small computers. Authors have generally chosen to use programs that follow graphical methods of calibration,[3-8] although some, like Margoshes and Rasberry,[9] take a different approach by assuming a linear relation between functions of the relative exposure and of the microphotometer readings. Most graphic methods studied appeared to be unduly complex; for example, data was generally converted to Seidel or "modified" Seidel transformations, the use of the principles involved in Kaiser transformations were employed, or dedicated computers were used.

Our laboratory has striven for a program that would follow our present, slightly modified ASTM method of calibration[10] which is simple in principle. We sought a computer method that would plot preliminary and emulsion calibration curves so that a convenient check could be made on the original data at any time desired. By retaining the ability to have curves printed by the computer one can decide, for instance, whether more points are needed to establish the preliminary curve, as it must be remembered that the accuracy of the final readout of any computer program is limited by the accuracy, number, and selectiveness of the original dark/light data read from the microphotometer.

Using our program, dark/light data are inputted to obtain the emulsion calibration equation. This equation is then stored either in the memory of the calculator or on recording tape. To find a relative intensity, percent transmission readings (one from the element in question and the other from an internal standard) are entered in the computer. Troubleshooting the emulsion calibration is simplified by printing the preliminary curve with the original data superimposed on it along with the emulsion calibration curve.

Two similar programs were originated to follow our existing "hand emulsion calibration" method. One program uses time-sharing computer facilities and has the capability of printing charts or tables of percent transmission and corresponding relative intensities. The other program uses a Hewlett-Packard (H.P.) 9830-A calculator with an 8K memory storage. An X-Y plotter is attached to plot curves originated by the data from the computer.

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3. HOLCOMBE, J. A., BRINKMAN, D. W., and SACHS, R. D. *Fortran-Based Photographic Emulsion Calibration Procedure for Use in Quantitative Spectrometry.* Analytical Chemistry, v. 47, March 1975, p. 441-447.
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5. ANDERSON, J. W., and LINCOLN, A. J. *General Mathematical Approach to Emulsion Calibration in Optical Emission Spectroscopy.* Applied Spectroscopy, v. 22, 1968, p. 753-757.
6. JOYCE, C. S. *The Use of a Digital Computer for Photographic Photometry and Spectrochemical Computations.* Canadian Spectroscopy, v. 10, 1965, p. 33-37, 43.
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8. SHAW, D. M. *Principles of Machine Computation of Spectrochemical Analyses.* Canadian Spectroscopy, v. 10, 1965, p. 3-6.
9. MARGOSHES, M., and RASBERRY, S. *Application of Digital Computers in Spectrochemical Analysis–Computational Methods in Photographic Microphotometry.* Spectrochimica Acta, v. 24B, 1969, p. 497-513.
10. *Methods for Emission Spectrochemical Analysis.* American Society for Testing and Materials, 1971.

## PROCEDURE FOR EMULSION PLATE CALIBRATION

Cassette, rotation, and position settings on the spectrograph were adjusted so that the wavelength region 2750 to 3450 Å could be photographed. A solution containing 50 mg/ml iron was sparked for a twenty- and forty-second exposure. Details concerning the parameters used for excitation and conditions set on the spectrograph are found in Appendix A. A seven-step filter, with segments in the ratio of 1:2, was placed between the spark and the entrance slit of the spectrograph to stepwise attenuate the exposure.

Using a densitometer, lines on the photographic plate in the wavelength region 3000 to 3200 Å were examined. Transmittances between 1.5% and 92% in the 66% and 33% portion of a line (the second and third step of the filter) were listed in a table labeled DARK percent T and LIGHT percent T. The preliminary curve (PC) is generated from data which consists of about 50 line pairs plotted and connected on linear graph paper. Paper 15" x 10" in size was labeled DARK percent T on the ordinate and LIGHT percent T on the abscissa. Formation of this curve is the first stage in the ASTM method.

The second stage of the method is the construction of the emulsion calibration or H and D curve and it is the equation of this curve that is ultimately used in relating percent transmission to relative intensity. To construct this curve a new table was established using the two parameters, percent T and NUMBER. A DARK percent T point was chosen on the preliminary curve as low in value as possible but above the intercept of the curve with the ordinate. A corresponding LIGHT percent T point was obtained and this value was written under percent T and 7 under NUMBER as in the table. Allowing the value of the LIGHT percent T to equal the numerical value of a DARK percent T point, a new LIGHT percent T value was obtained from the PC. In the table, 6 was placed under NUMBER and the new LIGHT percent T value recorded. This method was continued until LIGHT percent T values were obtained for the corresponding numbers 5, 4, 3, and 2.

Using standard size 8-1/2- x 11-inch, two-cycle semilog paper, the ordinate or log scale was labeled percent T (1-100) and the linear portion or abscissa was marked off from left to right, one to eight with ten divisions between marks. This axis was labeled NUMBER. Values from the table were plotted and a straight line was drawn connecting the two points corresponding to the values of 6 and 7 and extending to the abscissa axis. After establishment of this line, intermediary points between NUMBERS are taken so that the calibration curve can be drawn more accurately. This was accomplished by choosing an abscissa value between 7 and 8, for example, 7.5, and obtaining the corresponding percent T value from the straight line drawn on the emulsion calibration curve. This value was set equal to a DARK percent T point on the PC and referring back to that curve a corresponding LIGHT percent T value was determined. In the previously established table, place the value 6.5 under NUMBER (6.5 chosen because it is one less than 7.5, the starting value) and the newly obtained LIGHT percent T value under percent T. Continuing, let this new LIGHT percent T value equal that of a DARK percent T point on the PC and obtain a new LIGHT percent T number from the PC. In the table, place 5.5 under NUMBER and the newly obtained LIGHT percent T value under percent T. This procedure is continued until values have been added to the table for NUMBERS 4.5, 3.5, and 2.5. Additional starting

points such as 7.8, 7.6, etc., were chosen and the above example was followed to obtain numerous data points in order to precisely draw the emulsion calibration curve. Typical data points used to establish the preliminary and emulsion calibration curves are shown in Tables 1 and 2.

The emulsion calibration curve just completed was expanded to 15" x 10" semilog paper. The ordinate remained the same scale; however, the abscissa was expanded in such manner that two curves were plotted, one over the other. The NUMBER or abscissa axis scale is enlarged so that the NUMBERS 5 to 8 on the small calibration curve were expanded to full scale for the new curve. Starting with 5, each major division is in tenths and each minor division is equal to 0.02. The top abscissa of the new emulsion calibration curve expands the scale of the small calibration curve region NUMBERS 2 to 5 to full scale. The enlarged curve is completed using values from the table used to construct the small calibration curve.

The last stage of the calibration process involves construction of a rule. A cardboard approximately 28" x 1.5" is used as the starting material and a line is drawn dividing the cardboard in half in the long direction. Abscissa axis NUMBERS 2.0, 3.0, 4.0, 5.0, 6.0, and 7.0 are superimposed on the rule from the expanded calibration curve and marked off from the underside of the long line of the rule. This is done in such manner that approximately abscissa axis NUMBER 7.5 would be the last point at the right hand end of the rule.

With the rule aligned so that NUMBERS 7, 6, and 5 on the graph paper are in line with their corresponding NUMBERS on the rule, a right triangle is used to help superimpose the percent T ordinate values of the large emulsion calibration curve onto the rule and to mark off percent T readings on the upperside of the straight line of the rule. For example, using 2 percent T, one finds the intersection of the ordinate point 2% with the curve, aligns the long straight edge of the triangle at this point while the base of the triangle is parallel with the straight line of the rule, an alignment mark is made, and the NUMBER 2.0 is labeled. In this manner, percent transmissions between 2.0 and approximately 60.0 were marked off. The rule was then shifted so that abscissa axis NUMBERS 2.0, 3.0, and 4.0 on the calibration curve were aligned with the corresponding numbers on the rule and the remainder of the percent T scale was superimposed. The rule has the approximate range 92.0 to 2.0 percent transmission.

Table 1. TYPICAL RAW DARK AND LIGHT DATA POINTS USED TO ESTABLISH THE PRELIMINARY CURVE EQUATION

| Point | Dark | Light |
|---|---|---|
| 1 | 8.7 | 24.5 |
| 7 | 5.1 | 14.7 |
| 14 | 42.1 | 77.1 |
| 15 | 65.1 | 91.9 |
| 19 | 11.1 | 29.1 |
| 20 | 59.5 | 85.8 |
| 30 | 49.7 | 81.1 |
| 34 | 30.5 | 58.1 |
| 53 | 38.1 | 73.3 |
| 73 | 2.9 | 6.2 |

Table 2. TYPICAL LOG PERCENT TRANSMISSION AND NUMBER VALUES FOR ESTABLISHING THE EMULSION CALIBRATION EQUATION

| Point | Log Percent Transmission | Percent Transmission |
|---|---|---|
| 7 | 0.4047 | 2.54 |
| 6.6 | 0.5671 | 3.69 |
| 6.2 | 0.7295 | 5.36 |
| 5.8 | 0.8917 | 7.79 |
| 5.4 | 1.0528 | 11.29 |
| 5.2 | 1.1328 | 13.58 |
| 4.8 | 1.2907 | 19.53 |
| 4.3 | 1.4806 | 30.24 |
| 3.7 | 1.6859 | 48.52 |
| 3.3 | 1.7974 | 62.72 |
| 2.5 | 1.9318 | 85.47 |

After establishing the rule, one is then ready to interpret densitometer readings of lines on photographic plates in the calibrated wavelength region, corresponding to elements under study. A percent T for the known and for the internal standard is read from the glass emulsion. Going to the rule, and using an ordinary ruler graduated in 24 units to the inch which corresponds to the linear axis spacing on the semilogarithmic paper recommended, the relative intensity difference can be obtained. By setting the zero on the left end of the ruler on the higher percent T, one then notes the point on the ruler which corresponds to the other percent T. That number is the relative intensity for that pair of percent T values. Continuing this process for pairs of known and internal standard lines, an analytical curve can be established on semilog paper with the log axis labeled CONCENTRATION and the linear axis RELATIVE INTENSITY. From this curve unknown concentrations with known relative intensities can be determined. Typical preliminary and emulsion calibration curves and a rule are shown in Figures 1 to 3.

## HEWLETT-PACKARD CALCULATOR METHOD

The equation of the preliminary curve can be determined and the curve generated by a plotter by the use of the polynomial regression procedure outlined in the MATH PAC book furnished with the H.P. computer.[11] Following this method one inputs a set of data points (Figure 4), and coefficients of a polynomial up to the 20th degree using a least-square fit may be produced. The DARK percent T and LIGHT percent T data used to draw the preliminary curve (see method done by hand) was entered into the H.P. program. Various degrees of the polynomial were

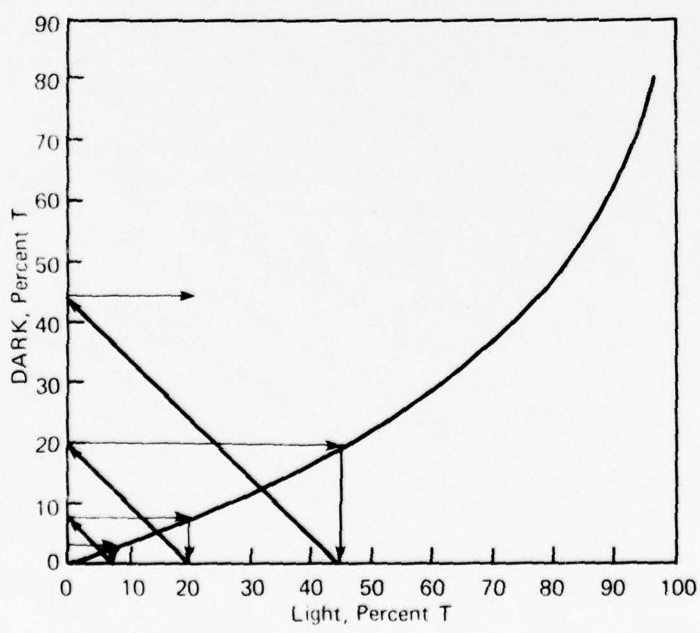



Figure 1. Preliminary curve, exemplifying method of successive determination of DARK %T and LIGHT %T values.

11. 9830 A MATH PAC, Model 30, Hewlett-Packard Calculator, v. 1.

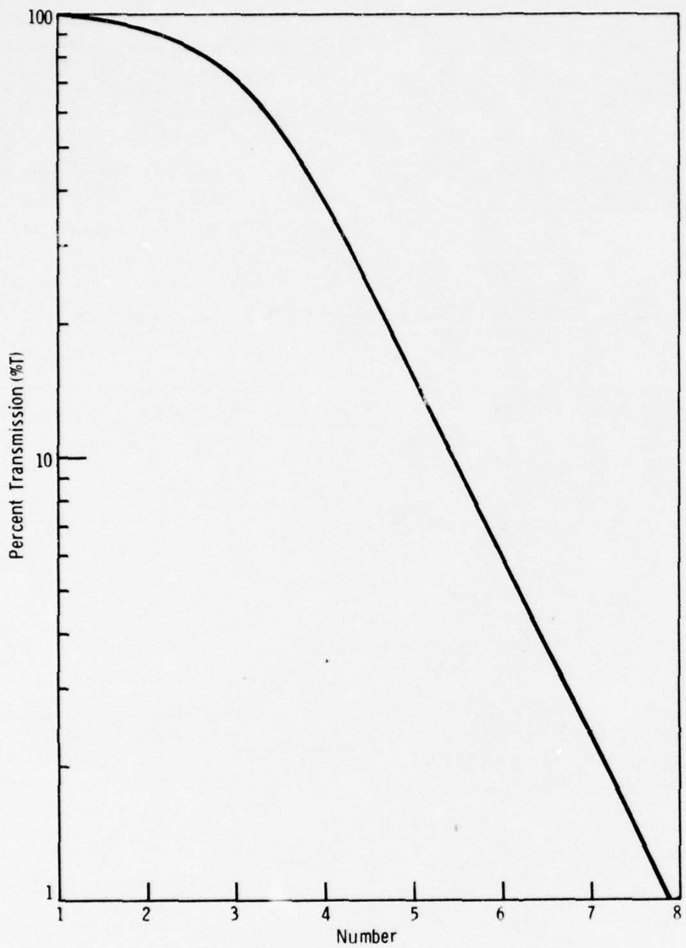



Figure 2. Emulsion calibration rule.

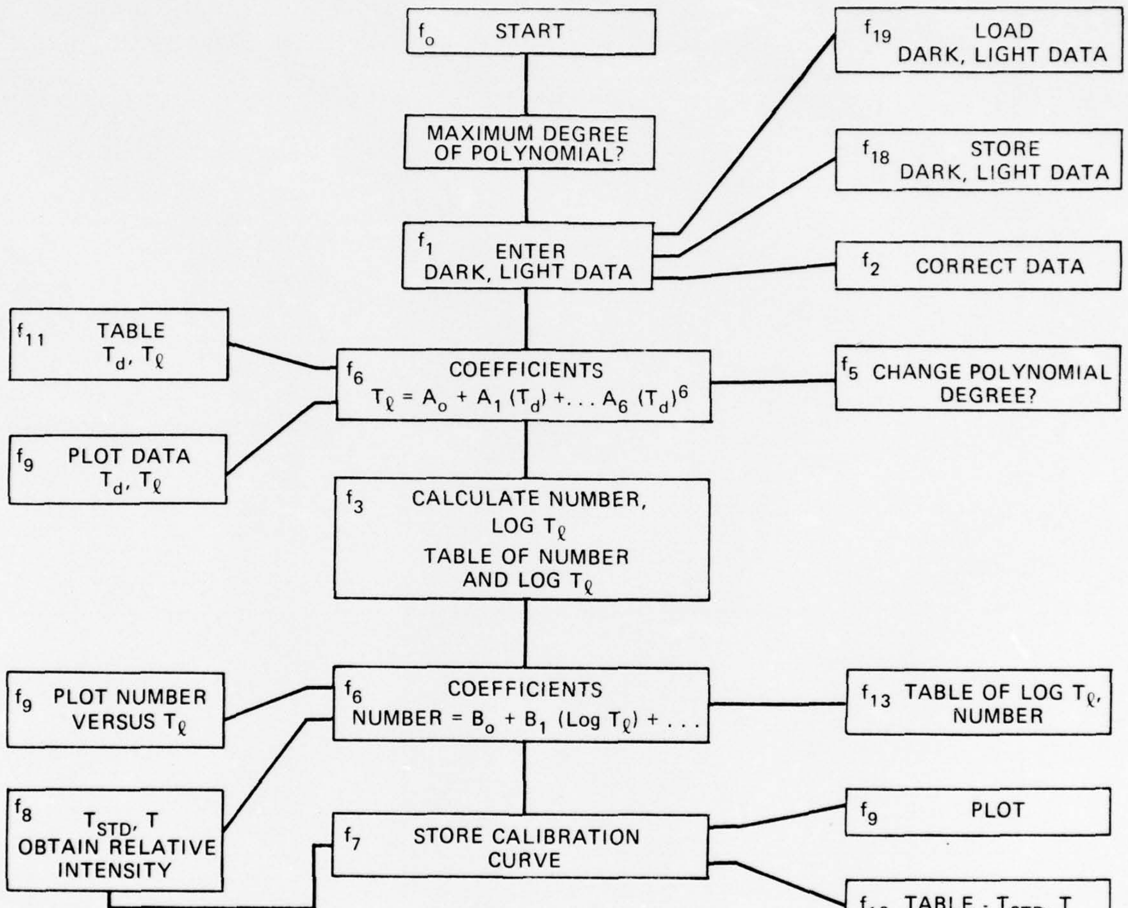

Figure 3. Condensed rule.

examined and it was found that a 6th degree gave a sufficiently high correlation coefficient for use. The following equation was used:

$$T_l = A_o + A_1 (T_d) + \ldots . A_6 (T_d)^6$$

where $T_l$ = percent transmission of light line
$T_d$ = percent transmission of dark line
$A_o$, $A_1$....coefficients of polynomial equation.

H. P. CALCULATOR OPERATIONS CHART




$T_\ell$ = Percent transmission of light line

$T_d$ = Percent transmission of dark line

Figure 4. H.P. calculator operations chart.

The data outputted contained DARK percent T values beginning with the number 1 and incremented in units of 1 to 80 along with corresponding LIGHT percent T values which are the calculated value for each DARK percent T point. Plotting the data, a smooth curve was obtained. This curve was superimposed on a hand-drawn curve from the original data and was found to be essentially identical.

Using the coefficients of the 6th degree polynomial, one generates a table labeled LIGHT percent T and NUMBER which is used to formulate the emulsion calibration curve. Referring to the above equation, let $T_d$ equal 1, solve the above equation for $T_l$ and store this value in the table along with the NUMBER 7. The computer sets $T_d = T_l$ and resolves the equation. In this manner, values in the table for $T_l$ are established for NUMBERS 7, 6, 5, 4, 3, and 2.

A linear curve is assumed between the data points NUMBER = 7, percent T = value found, and NUMBER = 6, percent T = value found. The straight line region is extended to percent T = 1, NUMBER = calculated value from the equation of the straight line. Solving this straight line equation, the computer is then able to take NUMBER values along this line and obtain corresponding $T_1$ values. For example, using the NUMBER value 7.5, a corresponding $T_1$ value is obtained from the equation of the straight line. This is set equal to $T_d$ and placed in the previous polynomial equation:

$$T_1 = A_o + A_1 (T_d) + \ldots . A_6 (T_d)^6$$

and a corresponding $T_1$ value is received. In the table $T_1$ and NUMBER, the $T_1$ value obtained and the NUMBER 6.5 (one less than 7.5), are stored. In similar fashion, NUMBER values from 6.9 to 2.1 in increments of one tenth are obtained.

The data from the table LIGHT percent T versus NUMBER is then used to generate the coefficients for the equation:

$$\text{NUMBER} = B_o + B_1 (\log T_1) + \ldots . B_6((\log T_1)^6.$$

A 6th degree polynomial furnished a high correlation coefficient.

Using the above equation, percent T for a known element (obtained from the density of the line on the glass plate emulsion) is substituted for the $T_1$ value. Solving the equation a value for NUMBER is obtained. The procedure is repeated for a percent T for an internal standard and another NUMBER is obtained. The computer subtracts these two NUMBERS and their difference is called RELATIVE INTENSITY. As outlined in the method done by hand, this process is continued for pairs of known and internal standard lines. An analytical curve is established on semilog paper with the log axis labeled CONCENTRATION and the linear axis RELATIVE INTENSITY. From this curve unknown concentrations with known relative intensities can be determined. Program used is presented in Appendix B.

## UNIVAC 1108 COMPUTER METHOD

Appendix C lists the UNIVAC 1108 program. The only input necessary for the program is the initial DARK/LIGHT data read from the emulsion-covered glass plate used for the calibration. Using these values, the computer can calculate coefficients of a polynomial equation to any practical degree required, and from the values obtained, the lowest degree polynomial with good correlation coefficient was chosen. The program then outputted least-square data of DARK/LIGHT points, that is DARK, LIGHT, and LIGHT FITTED, from which the preliminary curve may be drawn. If desired, a plot of this curve can be obtained.

Following the procedure outlined in the Hewlett-Packard Calculator Method, a table labeled LIGHT percent T and NUMBER is generated to formulate the coefficients of the emulsion calibration equation used as the equation of the emulsion calibration curve.

$$\text{NUMBER} = B_o + B_1 (\log T_1) + \ldots . B_n (\log T_1)^n$$

where $T_1$ = percent transmission of light line
$B_o \ldots B_n$ = coefficients of polynomial equation.

After determining the coefficients of the above equation with the UNIVAC 1108, the equation can be used with many small desk top calculators that do not have the memory needed to solve a 6th degree polynomial. By inserting the log of the percent transmission of an elemental line, one gets the value for NUMBER.

Assuming a calculator is not available, using the above equation, a chart of percent transmission and NUMBER may be generated. Percent T was varied in increments of 0.05 from 2 to 20 and in units of 0.1 from 20 to 90. The left vertical column of the chart lists changes in percent transmission by one unit, for example, from 20 to 21. The top row of the chart varies percent T by either 0.05 or 0.1 depending on the percent transmission range. The body of the chart contains NUMBER values. For example, if an intensity of an element of a standard sample line was measured at 50.5% T and that of an element internal standard line at 20.6% T, one would find the corresponding NUMBER value by proceeding horizontally along the chart from the extreme left column containing the number 50 as the first integer until one reaches the column headed by 0.5. This NUMBER value is then recorded. The procedure is repeated for the other transmission value of 20.6. The difference in NUMBER values is the relative intensity.

Various charts were attempted, including one in which two percent transmissions (for example, from the unknown element line and that of the internal standard) could be found in the first column and first row of the chart. The point of intersection, going horizontally and vertically along the chart from the two percent T values, is the relative intensity and the need of taking the difference in NUMBER for each percent T pair is eliminated. To accomplish this, however, the chart became very voluminous and it was found that the previously described chart was easier to use.

## CONCLUSION

A computer program that follows closely the ASTM graphic method has been developed for use on a Hewlett-Packard 9830-A and a UNIVAC 1108 time-sharing computer. For laboratories that do not have continuous access to these computers, one can obtain the coefficients to the equation relating percent transmission to relative intensity and then use the equation on small memory desk top calculators to find relative intensities.

The program used in the UNIVAC 1108 will output a table of percent transmission versus NUMBER which is used to obtain the relative intensity for a pair of percent transmission values.

## ACKNOWLEDGMENTS

The author is indebted to Dr. Gary L. Hagnauer for his assistance on the H.P. computer program, to Mrs. Anna M. Hansen for the help on the UNIVAC program, and to Mr. Frederick P. Valente who suggested this timesaving approach.

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A COMPUTER METHOD FOR THE CALIBRATION OF A PHOTOGRAPHIC EMULSION FOR SPECTROGRAPHIC ANALYSIS - Bernard H. Strauss

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## APPENDIX A. SPECTROGRAPHIC PARAMETERS

Equipment

- Baird 3-meter spectrograph, 2.75 Å/mm reciprocal linear dispersion
- Jarrell-Ash Varisource
- Jarrell-Ash Microphotometer

Instrumental Parameters

- Spark-18,000 V. A. C., 3 breaks per half-cycle, 6 to 6.5 amperes
- Analytical gap-3 mm
- Auxiliary gap-6 mm
- Sample electrode-Ultra Carbon 106
- Counter electrode-Ultra Carbon 105 U
- Pre-spark duration-20 sec.

Photographic Parameters

- Plates-Eastman Kodak SA 1
- Developer-Eastman Kodak D19
- Developing time- 3.5 min.
- Developimg temperature 20°C

Spectral range of calibration 2750-3450 Å

Spectral lines read in range of 3000-3200 Å

APPENDIX B. HEWLETT-PACKARD CALCULATOR PROGRAM FOR GLASS PLATE EMULSION CALIBRATION

$f_o$

```
10   For I=1 to 22
20   C [I] = B [I] = 0
30   Next I
40   For I = 23 to 253
50   C [I] = 0
60   Next I
70   B [I] = I
80   W = N = S1 = S2 = S3 = S4 = S5 = I1 = 0
90   Disp " Max Degree Polynomial ";
100  Input D2
110  Print " Max Degree Polynomial = " D2
120  D1 = D2
130  Print
140  End
```

$f_1$

```
10   Format F 4.0, 2 F 12.4
20   Print "Enter Prelim Calibrn Data"
30   If N ≠ 0 then 70
40   Print "No." Tab 10" Dark "Tab 22 "Light"
50   I1 = 0
60   I1 = I1 + 1
70   Disp "Dark, Light =";
80   Input G[I1], H [I1]
90   Y = H [I1]
100  B [2] = G[I1]
110  Write (15, 10) N+1, G [I1], H [I1]
120  Y = FN X 1
130  Go to 60
140  End
```

$f_2$

```
10   If W = 0 then 40
20   Disp " Not allowed"
30   End
40   Disp " Wrong No., Dark, Light =";
50   Input I, Y, B [2]
60   G [I] = Y
70   H [I] = B [2]
80   Print "Delete: Dark = "G[I]" Light = "H [I]
90   Y = FNX (-1)
100  Disp
110  End
```

$f_3$

```
10   I1 = 0
20   Print " Polynomial Degree = "D1
30   Print "Relative I Log T  Light "
40   X2 = 1
50   X = 1
60   X1 = 8
70   If X1< = 2 then 210
80   Y = B[D1 +1]
90   For J = D1 to 1  Step -1
100  Y = Y * X + B[J]
110  Next J
120  X=Y
130  If X>100 then 210
140  X1 = X1-1
150  If X1< = 2 then 210
160  I1 = I1 + 1
170  H [I1] = X1
180  G [I1] = L G T X
190  Print X1, G [I1], X
200  Go to 70
210  X2 = X2 - 0.1
220  If X2 = 0 then 290
230  I1 = I1 + 1
```

```
240   G [11] = (G [2] - G [3]) * X2 + G [2]
250   X1 = 6 + X2
260   X = 10↑G [11]
270   H [11] = X1
280   Go to 190
290   Y = FN Y1
300   End
```

$f_4$

```
10    Def FNX (Z)
20    For I = 2 to D2
30    B [I+1] = B [I] * B [2]
40    Next I
50    B [ D2 + 2] = Y
60    R = 0
70    For I = 1 to D2 +2
80    For J = I  to D2 + 2
90    R = R+1
100   C [R] = C [R] + B [I] * B[J] * Z
110   Next J
120   Next I
130   S1 = S1 + B [2] * Z
140   S2 = S2 + B [2]↑2 * Z
150   S3 = S3 + Y * Z
160   S4 = S4 + Y *Y * Z
170   S5 = S5 + B [2] * Y * Z
180   N = N + Z
190   Return 0
```

$f_5$

```
10    Disp " New Polynomial Degree =";
20    Input D1
30    Print " Degree of Polynomial =" D1
40    End
```

$f_6$

```
10    If N< = D2 - W then 340
20    If D1< = D2 - W then 50
30    Disp " Max Deg ="; D2 - W
40    End
50    If W = 0 then 330
60    T = 0
70    For I = 1 to D1 + 1
80    B [I] = 0
90    For J = 1 to D1 - I + 2
100   R = ( I + J - 1) * D2 + 2 - 0.5 * ( I + J ))
110   B [I] = B [I] + C [ T + J] * C [R]
120   Next J
130   T = I * ( D2 + (3-I) / 2)
140   Next I
150   R1 = 0
160   For I = 2 to D1 + 1
170   R1 = R1 + C [I*(D2 + (3-I) / 2]↑2
180   Next I
190   T0 = C [(D2 + 1) * (D2+2) / 2]
200   T0 = T0 - C [D2 + 1]↑2
210   Print
220   Print " Coefficients"
230   Print
240   Format F3.0, E 12.4
250   For I = 1 to D1 + 1
260   Write (15, 240) " B ("I-1") = "B[I]
270   Next I
280   Print
290   Print
300   Print "R Square = " R1/T0
310   Print
320   End
330   If N > D2 then 360
340   Disp " Not Enough Points"
350   End
360   P = W = 1
```

```
370    D2 = D2 + 1
380    For J = 1 to D2
390    Print C [P]
400    C [P] = SQR C [P]
410    For I = 1 to D2 - J+1
420    C [P+I] = C [P+I] / C [P]
430    Next I
440    R = P + 1
450    S = R
460    For L = 1 TO D2 - J
470    P = P + 1
480    For M = 1 to D2 + 2 - J - L
490    C [ R+M - 1] + C [ R+M-1] - C [P] * C [P+M-1]
500    Next M
510    R = R + M - 1
520    Next L
530    P = S
540    Next J
550    T = ( D2 + 1) * ( D2 + 2) /2
560    For I = 1 to D2 - 1
570    T = T - 1 - I
580    C [T] = 1 / C [T]
590    For J = 1 to D2 - I
600    P = D2 + 1 - I - J
610    P = P * ( D2 + 1 - (P-1) /2) - I
620    R = P-J
630    S = 0
640    U = I + J + 1
650    Y = P
660    For K = 1 to J
670    Y = Y + U - K
680    S = S - C[R+K] * C [Y]
690    Next K
700    C [P] = S / C [R]
710    Next J
720    Next I
730    C [1] = 1/ C [1]
740    Go to 60
```

$f_7$

```
10     B [22] = D1
20     Print " Store X = F ( Log  T) Calibration "
30     Disp " Store File # = " ;
40     Input I
50     Print " Store File # " I
60     Store Data I, B
70     End
```

$f_8$

```
10     Print " Diff X Evaluation"
20     Disp " T (STD), T = ";
30     Input T1, T2
40     Print " T (STD) = "T1
50     Print " T = " T2
60     T1 = LGTT1
70     T2 = LGTT2
80     X1 = X2 = B [D1 + 1]
90     For J = D1 to 1 Step - 1
100    X1 = X1 * T1 + B [J]
110    X2 = X2 * T2 + B [J]
120    Next J
130    Print " X (STD) = " x1
140    Print " X = " X2
150    Print " X (STD) - X = "X1-X2
160    Go to 20
170    End
```

$f_9$

```
10     Disp "Re-plot Axis";
20     Input Z9
30     If Z9 = 0 then 390
```

```
40   Disp "X (Max) = ";
50   Input B2
60   Disp "X (Min) = ";
70   Input A2
80   Disp "Y(Max) = ";
90   Input B1
100  Disp "Y (Min) = " ;
110  Input A1
120  C2 = (B2 - A2) / 10
130  C1 = (B1 - A1) / 10
140  Scale A2, B2 + 2*C2, A1, B1, + 2*C1
150  Plot A2 + (B2 - A2) /2.2, A1 + C1 /4
160  Label (*, 3, 2, 0, 2/3)
170  Letter
180  Plot A2 + C2/4, A1 + (B1 -A1)/2.2
190  Label (*, 3, 2, PI/ 2, 2/3
200  Letter
220  Offset C2, C1
230  XAXIS A1, C2, A2, B2
240  YAXIS B2, C1, A1, B1
250  YAXIS A2, C1, A1, B1
260  XAXIS B1, C2, A2, B2
270  Label (*, 2, 1.7, 0, 2/3)
280  For Y = A1 to B1 Step 2*C1
290  Plot A2, Y, 1
300  CPLOT -5.4, -0.34
310  Label (380, 2, 1.7, 0, 2/3) Y
320  Next Y
330  For X = A2 to B2 step 2*C2
340  Plot X, A1, 1
350  CPLOT -3.8, -1
360  Label (380, 2, 1.7, 0, 2/3) X
370  Next X
380  Format F 5.1
390  For X = A2 to B2 Step C2/10
400  Y = B [D1 + 1]
410  For J = D1 to 1 Step -1
420  Y = Y * X + B [J]
430  Next J
440  Plot X,Y
450  Next X
460  Disp "Plot Data Points";
470  Input Z9
480  If Z9 = 0 then 550
490  PEN
500  For K = 1 to 11
510  Plot G[K], H [K]
520  CPLOT -0.3, -0.3
530  Label (*) "0"
540  Next K
550  PEN
560  Plot -1.2 * C2, -C1
570  PEN
580  Go to 10
```

$f_{11}$

```
10   Format 2F 12.4
20   Print Tab 9 "X Dark "Tab 21" Y Light"
30   For I = 1 to 79 Step 2
40   Y = B [D1 + 1]
50   For  J = D1 to  1  Step -1
60   Y = Y* I + B [J]
70   Next J
80   Write (15, 10) I, Y
90   Next I
100  For I = 80 to 100 Step 1
110  Y = B [Di + 1]
120  For J = D1 to 1 Step -1
130  Y = Y * I + B[J]
```

```
140    Next J
150    Write ( 15, 10) I, Y
160    Next I
170    End
```

$f_{13}$

```
10     Format 2 F 12.4
20     Print Tab 9 "X" Tab 21 "T"
30     For I = 0.3 to 2  Step 0.05
40     Y = B [D1 + 1]
50     For J = D1 to 1 Step -1
60     Y = Y * I + B [J]
70     Next J
80     Write (15, 10) Y, 10↑I
90     Next I
100    End
```

$f_{14}$

```
10     Def FNY(Z)
20     Disp "Max Degree Polynomial";
30     Input D2
40     Print "Degree Polynomial = "D2
50     Di = D2
60     Print I1
70     For I = 1 to 22
80     C [I] = B[I] = 0
90     Next I
100    For I = 23 to 253
110    C [I] = 0
120    Next I
130    I3 = 0
140    B [1] = 1
150    W = N = S1 = S2 = S3 = S4 = S5 = 0
160    I3 = I3 + 1
170    B [2] = G [I3]
180    Y = H [I3]
190    Y = FN X1
200    Print I3, G[I3], H [I3]
210    IF I3 = I1 - 1 then 230
220    Go to 160
230    End
```

$f_{17}$

```
10     Print "Load X = F (LOG T) Calibration"
20     Disp  "Load File # = ";
30     Input I
40     Print "Load File # "I
50     Load Data I, B
60     Di = D2 = B [22]
70     Print "Degree Polynomial = "D1
80     End
```

$f_{18}$

```
10     Disp "Store Data, File # = ";
20     Input I
30     Store Data I
40     End
```

$f_{19}$

```
10     Disp "Load Data, File # = ";
20     Input I
30     Load Data I
40     Format F 4.0, 2 F 12.4
50     Print "No." Tab 10 "Dark" Tab 22 "Light"
60     I1 = 0
70     I1 = I1 +1
80     Y = H [I1]
90     B[2] = G [I1]
100    Write (15, 40) N + 1, G [I1], H[I1]
110    Y = FNX1
120    Go to 70
130    END
```

# APPENDIX C. UNIVAC 1108 PROGRAM

```
      DIMENSION X(1200), Y(1200), W(200), T1(200), T2(200), T3(200),
    1 C(11), ALPHA(10), BETA(10),
      DIMENSION S(4), YF(400), A(14)
105   FORMAT (/// 29H OUTPUT FROM SUBROUTINE FITY.//7H IND 3 = I 3///3X
      2H 1X, 18X 2HY, 14X 9H Y FITTED // (1H 1P3E 20.7))
103   FORMAT (///31H OUTPUT FROM SUBROUTINE ORTHLS.//7H IND 1 = 13//2X
    1 2HI, 13X 2H C, 16X 6H ALPHA, 14X 5H BETA/1H I4, 1PE 20.7/
    2 (1H I4, 1P3E 20.7))
104   FORMAT (/// 30H OUTPUT FROM SUBROUTINE COEFS.//7H IND 2 = I3//13X
    1 2HI, 17X 5H A(I)//(1H I14, 1PE 26.7))
      P = 3.141592654
      READ 1,N,K
      READ 1, NUM, NUMA, DUM
    1 FORMAT (I5, I5, F10.0)
      DO 10 I = 1, N
      READ 2, X(I), Y(I)
   10 CONTINUE
    2 FORMAT (F10.0, F10.0)
  101 L = 0
      J = 0
      CALL ORTHLS (X, Y, W, N, L, J, C, ALPHA, BETA, K, T1, T2, T3, IND1)
      IT = 0
      WRITE (6, 103) IND 1, II, C(1), (II, C(II + 1), ALPHA (II), BETA (II),
    1 II = 1, K)
      DO 15 MM = 1,K
      KF = MM
      CALL FITY (X, N, J, C. ALPHA, BETA, KF, YF, T1, T2, IND 3)
      WRITE (6, 105) IND 3, (X(I), Y(I), YF(I), I = 1, N)
      CALL COEFS (J, C, ALPHA, BETA, KF, A, T1, T3, IND 2)
      IT = 0
      WRITE (6, 104) IND2, II, A(1), II, A(II + 1),
      II = 1, KF)
   82 FORMAT (1H1)
   81 FORMAT (1H 3E 15.6)
      MB = MM +1
   15 CONTINUE
      PRINT 82
      DO 80 IA = 1, N
      ANS = A(1)
      DO 75 II = 2, MB
      FIB = II -1
   75 ANS = ANS + A(II) *X(IA)* FIB
      IF (IT. EQ.3) X(IA) = EXP (X(IA))
   80 PRINT 81, X(IA), Y(IA), ANS
```

```
      IF, (IT.EQ.3) GO TO 102
      PRINT 82
      AB = 1.0
      SAVE = SOLVE (A, AB, MB)
      PRINT 85, SAVE, AB
      SAVE = SOLVE (A, SAVE, MB)
      PRINT 85, SAVE 1, SAVE
      CON = ALOG (SAVE)
      CON 1 = ALOG (SAVE 1)
      D = CON1-CON
      Y(1) = ALOG (SAVE)
      X(1) = 7
      S(1) = SAVE
      DD = D/10
      DO 650 I = 2, 10
      S(I) = EXP (CON + DD * (I - 1))
      X(I) = 7. -(I-1)*.1
650   Y(I) = ALOG (S(I))
      L = 10
      DO 651 J = 1, 10
      AB = S(J)
      DO 652 JJ = 1,4
      L = L + 1
      ANS = SOLVE (A, AB, MB)
      Y(L) = ALOG (ANS)
      X(L) = X(J) -1.0 * JJ
      IF (ANS. GE. 100.) GO TO 653
      PRINT 85, ANS, AB, X(L)
652   AB = ANS
      GO TO 651
653   L = L-1
651   CONTINUE
      IT = 3
      N = L
      DO 107 J = 1, N
      TEM = X(J)
      X(J) = Y(J)
107   Y(J) = TEM
      GO TO 101
102   CONTINUE
      NUMB = NUM + 10
      NUMC = NUMA + 1
      DO 111 I = 1, NUMB
      X(I) = DUM
      IF (I. GT. NUMC) X(I) = X(1) + .05
```

```
      AB = ALOG (X(I))
      Y(I) = SOLVE (A, AB, MB)
111   DUM = X(I) + .05
      PRINT 17
      WRITE (6, 18)
      DO 40 I = 1, NUMA, 20
      JJ = I + 19
 40   WRITE (6, 19) X(I), (Y(J), J = I, JJ)
      NUMB = JJ + 1
      IPRINT = NUMB + 500
      PRINT 17
      WRITE (6, 13)
      DO 150 I = NUMB, NUM, 10
      JJ = I + 9
      IF(I. GT. IPRINT) GO TO 16
      GO TO 150
 16   IPRINT = I + 500
      PRINT 17
      PRINT 13
150   WRITE (6,11) X(I), (Y(J), J = I, JJ)
 19   FORMAT (1H 21F6.2)
 18   FORMAT (16 X, '.05' 3X, '.10' 3X, '.15' 3X, '.20 3X, '.25'
      3X, '.30',
  1   3X, '.35' 3X, '.40' 3X, '.45' 3X, '.50' 3X, '.55' 3X, '.60' 3X, '.65'
  2   3X, '.70' 3X, '.75' 3X, '.80' 3X, '.85' 3X, '.90' 3X, '.95'
 11   FORMAT (1H F6.2, 10F8.2)
 13   FORMAT (1H 19X '.1', 6X '.2', 6X '.3', 6X '.4', 6X '.5', 6X '.6',
      6X '.7', 6X '.8', 6X '.9')
 17   FORMAT (1H1)
 85   FORMAT (1H 'Y 1 = ' F13.8, 5X, 'X1 = ' F13.8, E14.8)
      STOP
      END
```

LEGEND

N = No. OF EXPERIMENTAL POINTS

K = MAXIMUM ORDER OF EQUATION FOR POLYNOMIAL LEAST SQUARES FIT.

NUM = TOTAL NUMBER OF PERCENT TRANSMISSION vs RELATIVE INTENSITY VALUES IN TABLE

NUMA = TOTAL NUMBER OF PERCENT TRANSMISSION VALUES OF INCREMENT .05 IN TABLE

DUM = INITIAL VALUE OF PERCENT TRANSMISSION PRINTED IN TABLE (2.0 USED IN THIS WORK)

X(I) = EXPERIMENTAL DARK PERCENT TRANSMISSION

Y(I) = EXPERIMENTAL LIGHT PERCENT TRANSMISSION

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